Management of Root Fractures

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Abstract: Horizontal root fractures are frequently occurring consequences of acute traumatic dental injury (TDI). They are described as fractures separating the root into coronal and apical segments, with the fracture lines being completely or partially confined within the bone. Depending on the degree of injury, different treatment regimens may be applied. However, because the overall prevalence of root fracture is low, health-care professionals are often insecure regarding appropriate management. In general, root fracture treatment aims to preserve the functional integrity and aesthetics of the teeth involved. Treatment failure may eventually lead to tooth loss, with potentially negative lifetime consequences, such as impaired orofacial development. Altogether, it is indispensable for the health-care professional to know the biological foundation, diagnostic approaches and appropriate treatment modalities for root-fractured teeth. This chapter provides information on all these aspects, as well as the currently recommended recall regime and expected outcomes.

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Chapter: Management of Root Fractures

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3.1 Abstract

Horizontal root fractures (RF) are frequently occurring consequences of acute traumatic dental injury (TDI). They are described as fractures separating the root into coronal and apical segments, with the fracture lines being completely, or partially confined within the bone. Depending on the degree of injury, different treatment regimens may be applied. However, because the overall prevalence of RF is low, healthcare professionals are often insecure as to the appropriate management of an RF injury. In general, RF treatment aims to preserve the functional integrity and aesthetics of involved teeth. Treatment failure may eventually lead to tooth loss, with potentially negative lifetime consequences such as impaired orofacial development. Altogether, it is indispensable for the healthcare professional to know the biological foundation, diagnostic approaches, and appropriate treatment modalities for RF teeth. The information compiled here should provide the reader with an update on these aspects. Further, the currently recommended recall regime is presented and the outcome to be expected is discussed.

3.2 Introduction

TDI describes injury to teeth and/or other tissues of the oral cavity (such as the gums, periodontium, or alveolar bone) and their adjacent soft tissues (lips, tongue, cheek). The main reasons for TDI are accidents happening at sports, play or traffic, which by definition occur unexpectedly (Skaare and Jacobsen 2003). They are prevalent at all age groups and constitute approximately 5% of all (non-oral) injuries (Petersson et al. 1997). Overall, TDI occur most frequently during childhood and adolescence (Bücher et al. 2013a). Depending on the impact (force, vector) and the stage of tooth/root development, TDI can cause different forms of injury, including: crown fractures, luxation, avulsion, or RF. RFs, however, are rare and are present in merely 8% of all TDI cases (Andreasen et al. 2007, Andreasen et al. 2004b).

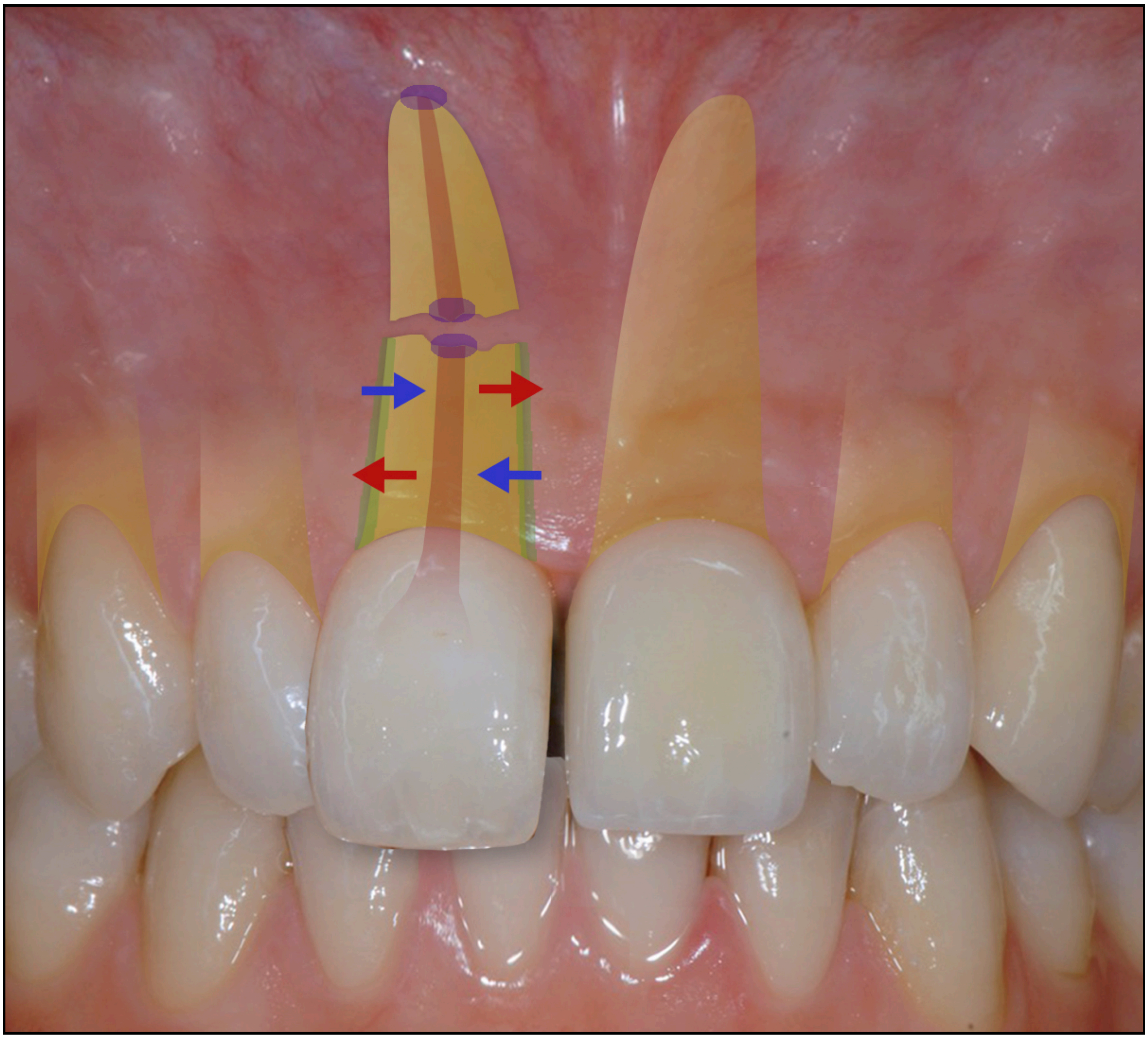
Because of the protrusion and therefore exposed position, maxillary permanent incisors are the teeth mostly involved in RF (Andreasen 1970). In contrast, deciduous teeth or teeth without finished root development are rarely affected (Majorana et al. 2002). The sponge-like bone structure surrounding deciduous teeth is known to be pliable and provides, similar to permanent teeth without finished root development, less periodontal support *(see Chapter Lussi/Schaffner)*. Hence, such teeth rather luxate, or avulse during TDI (McTigue 2009, Andreasen and Hjorting-Hansen 1967). The biological principles of a RF in deciduous teeth are not very different from those of permanent teeth. Consequently, they will be dealt with together in this chapter, while relevant differences will be presented separately.

3.3 Biological Considerations

If an injured tooth suffers a RF, different tissues are involved: the root itself, the supporting periodontium (periodontal ligament, cementum, and alveolar bone), the pulp, and gingival soft tissues (Figure 1). A TDI may result in an incomplete RF, complete RF, or even multiple complete RFs. The RF itself can extend in different angulations and may be located at any given level of the root. However, most frequently RFs occur at the mid-root level and are less common at the cervical, or apical levels (Calişkan and Pehlivan 1996, Andreasen et al. 2012b, Hovland 1992). The biological conditions and the treatment of supracrestal RF is more comparable to the treatment of crown-root fractures (Heithersay and Moule 1982) and therefore dealt with elsewhere in this book *(see Chapter Krastl & Bühler)*. A complete RF separates the root in two fragments; an apical and a coronal counterpart. Whereas the apical fragment commonly remains uninjured and in its natural position, the coronal fragment is frequently displaced from its alveolar bone socket and is therefore comparable to a (lateral) luxation injury. The impact provokes stretching/tearing of the periodontium on some parts of the coronal root surface, whilst compression occurs at the opposing areas (Figure 1). The tissue damage will inevitably result in local inflammation. However, if the coronal fragment is repositioned close to its natural position in a timely fashion and kept in place, the inflammation will ultimately lead toward periodontal repair. During reorganization, the periodontal tissues may undergo different forms of resorption. Histologically and radiographically, external and internal surface resorption are described, as well as internal tunneling resorption, and transient apical breakdown (Andreasen and

Andreasen 1988). External and internal surface resorption refer to the resorptive blunting of the external (proximal), or internal (central) root fracture edges. Internal tunneling resorption is described as a burrowing behind the pre-dentin layer along the root canal walls affecting the coronal fragment, and transient apical breakdown as a temporary resorption of the periodontium from the apical fragment (Andreasen 2003). Collectively these processes aim to remove damaged periodontal tissue and replace it by mineralization. They occur predominantly in the first two years after RF and can eventually be detected radiographically (Andreasen and Andreasen 1988). Clinically, they are of low concern and described in more detail elsewhere (Andreasen and Andreasen 1988, Andreasen 2003). However, they should not be confused with pathological events such as external replacement resorption, inflammatory root resorption, or periodontitis caused by root canal infection (Andreasen et al. 2007).

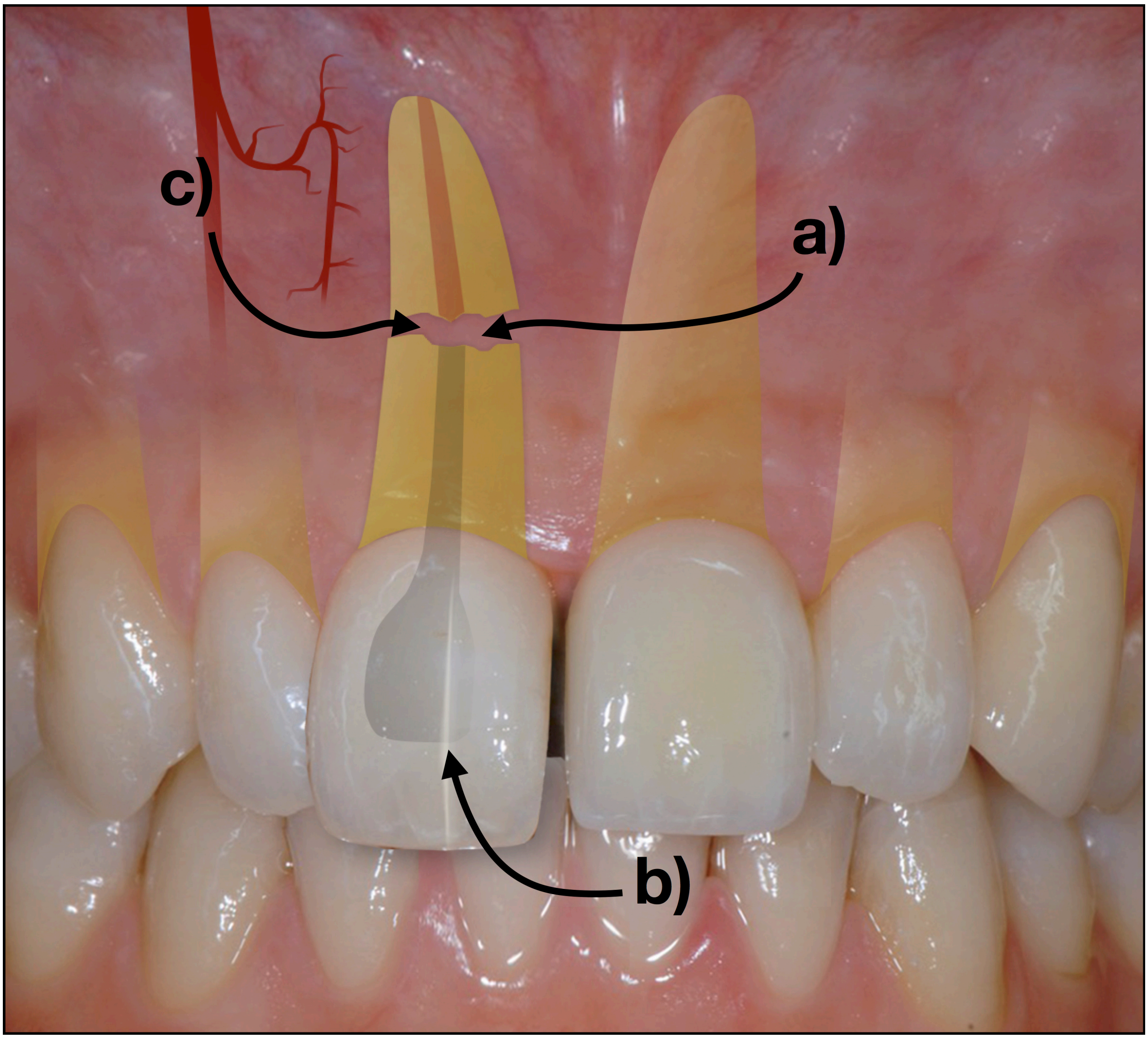
Figure 1. Tissues affected by root fracture injury: pulp (purple) and periodontium (green). The periodontal tearing, and compression site is indicated with a with a blue and red arrow, respectively.



In addition to the periodontium, the pulp is another important tissue affected by RF (Figure 1). It must be remembered, that TDI are most prevalent in children and adolescents, and maxillary incisors represent the teeth mostly affected (Bücher et al. 2013a, Andreasen 1970). These teeth are mostly free of caries and restorations (Steiner et al. 2010). Consequently, in most cases of RF, the pulp is in a perfectly healthy, immunocompetent condition when the injury occurs. The pulpal trauma can range from stretching and tearing of the neurovascular bundle to a total rupture of the nerve-vessel bundle. Even if the pulp ruptures because of a severely dislocated coronal root fragment, the apical fragment usually maintains its vitality since it is not affected by displacement and receives unimpeded neurovascular supply (Andreasen et al. 2004a, Andreasen et al. 2004b). The neurovascular supply of the coronal fragment, on the other hand, may be either compromised or entirely interrupted. In the latter case, the coronal aspect of the pulp initially becomes ischemic and finally develops a coagulation necrosis (Andreasen 1988). If the displaced coronal fragment receives appropriate treatment, including repositioning and flexible splinting, the chances for pulpal revascularization, and consequently the maintenance of pulpal vitality, are fairly good (Andreasen et al. 1989). Preserving pulpal vitality is desired, since a vital pulp provides immune-competence and facilitates continuing root development/hard tissue formation.

Depending on the periodontal and pulpal damage, as well as different patient and treatment-related factors, a RF may heal in either a desirable, or undesirable fashion (Heithersay and Kahler 2013). One factor of utmost importance for the outcome of RF is the potential access of microorganisms to the injury site. Microorganisms from the oral environment may gain direct access through a breach in the tissues (Figure 2). If the RF is located more towards the cervical root level, the risk for microbial infection increases significantly (Andreasen et al. 2012b, Welbury et al. 2002). In case of concomitant coagulation necrosis of the coronal fragment, the pulpal space may become infected and cause (apical) periodontitis (Nair 1997). If there is no access for microorganisms (i.e. aseptic trauma), healing may take place unaffected from infection, even if the pulp of the coronal fragment has become necrotic (Bender and Freedland 1983). However, over time, the chances increase that microorganisms will access the necrotic pulp space through cracks in the enamel and dentin, or possibly through anachoresis (Figure 2) (Love 1996, Grossman 1967). However, the latter route for microbial infection is mentioned here for the sake of completeness, and not supported by much evidence.

Figure 2. Routes for microbial infection of the root fracture injury site: a) through a trauma-caused breach in the tissues, connecting the injury site with the oral environment, b) via enamel/dentin cracks, c) through anachoresis, i.e. via blood-borne microbial infection.



Regardless of the presence of microorganisms, pulpal and periodontal healing at the RF site may be synergistic or competitive. Depending on which of the tissues dominates the healing process, different outcomes are described histologically (Hammer 1939, Schindler 1941, Kronfeld 1935, Andreasen and Hjorting-Hansen 1967, Andreasen and Andreasen 1988):

1) Hard tissue healing
   This form of healing is referred to when the fracture space between the apical and the coronal fragments is solidly bridged by hard-tissue deposition. Pulpal odontoblasts and periodontal cells serve as the source for a mixed pulpo-periodontal tissue (dentin, osteodentin, and cementum). Remaining pulpal vitality is a prerequisite for this most favorable type of healing.

2) Connective tissue healing
   Periodontally-derived connective tissue occupies the fracture gap between the fragments. It is assumed that the pulp must have suffered moderate damage for developing this healing pattern, thus periodontal (instead of pulpal) cells dominate the healing process. Ultimately this results in an organized, cementum-covered periodontal ligament, separating both fragments from each other.

3) Interposition of granulation tissue
   If microorganisms have access to the RF, infection of the coronal and apical aspect of the pulp may occur. This situation may be viewed as an (ordinary) necrotic root canal infection. Proteolytic enzymes and bacterial byproducts cause soft tissue breakdown and bone resorption between the fragments. Finally, inflamed granulation tissue interposes the RF gap. Consequently, this third outcome is not healing, but can still represent a steady-state situation without clinical signs or symptoms.

Having understood the biological foundation of the tissues involved, the diagnosis and therapy of teeth affected by RF become apparent: the treatment should aim to create an environment that (1) enables undisturbed periodontal healing, and (2) facilitates the maintenance of pulpal vitality.

3.4 Diagnostics of Root Fractures

The primary diagnostic goal is to recognize and distinguish a RF from other TDI, such as: crown-root fracture, intrusion, or luxation injuries. All diagnostic test results should be compared to those obtained with non-affected adjacent and/or contralateral teeth. In order to avoid missing any potentially relevant diagnostic information, using a systematic approach is recommended and shown to be beneficial in the management of TDI (Bücher et al. 2013b).

3.4.1 Inspection

In contrast to teeth with crown fracture, or crown-root fracture, RF teeth cannot be confirmed by direct visual inspection. The position of a root fractured coronal fragment may be unaltered, intruded, extruded, or laterally luxated. Patients may complain about occlusal interference. A slightly extruded, and toward the lingual, or palatal aspect displaced coronal fragment, is most prevalent (Feiglin 1995). However, based on clinical examination alone, it is not possible to differentiate a RF from a (lateral) luxation injury. Discoloration of the tooth crown after RF injury is infrequent (Malmgren and Hubel 2012). Nevertheless, rarely a reddish discoloration may evolve at short-term (2-3 days); a so-called transient coronal discoloration. This discoloration is caused by extravasation of blood into the dentinal tubules (Kronfeld 1935). As the name indicates, it is a temporary phenomenon that disappears, in most of the cases, within weeks or months (Malmgren and Hubel 2012).

3.4.2 Mobility

The coronal fragment may show increased mobility due to periodontal compression. This may be tested by gentle palpation of the tooth crown. An increased mobility of multiple teeth in unison may be suggestive for alveolar process fracture. Sometimes the coronal fragment shows no mobility during palpation at all. This is indicative for intrusion and may be confirmed by percussion (see below).

3.4.3 Probing depth

Forceful periodontal probing of traumatized teeth, in general and to confirm a potential fracture line in particular, is not advisable since it may cause additional trauma to the periodontium.

3.4.4 Percussion

Gentle tapping and percussion on the tooth crown may elicit some form of pain or periodontal discomfort. This suggests periodontal involvement in the injury. A non-mobile, intruded tooth fragment may provoke a characteristic high-pitched, metallic sound during percussion, similar to that of an ankylotic tooth.

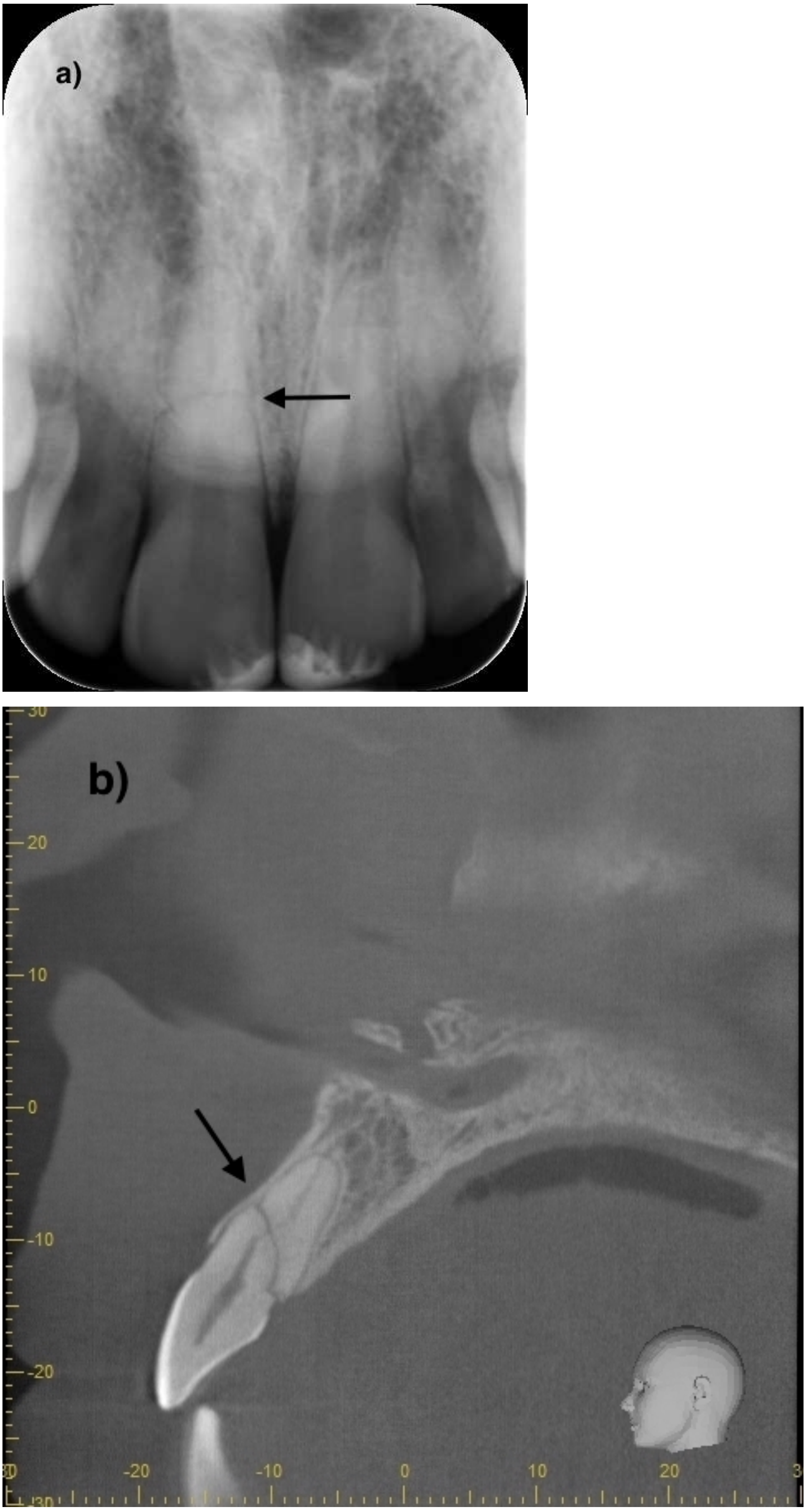
3.4.5 Pulpal sensitivity tests

Pulpal sensitivity tests are highly subjective (i.e. depending on the patient’s response) and in general not a perfect measure (Dummer et al. 1980). The most common sensitivity tests comprise the application of a thermal stimulus (cold test), or electric current (electric pulp test, EPT) to the tooth to be tested. These tests aim to evoke a neurogenic response by direct (EPT), or indirect (thermal) stimulation of pulpal nerve fibers. Hence, a positive test response indirectly suggests neurogenic activity and is highly indicative of vital pulpal conditions (Seltzer et al. 1965, Villa-Chavez et al. 2013). In contrast, the significance of a negative test result is limited (Seltzer et al. 1965, Andreasen et al. 1989, Gazelius et al. 1988). Yet a non-responsive pulp is a common finding after traumatic RF. It may be attributed some form of injury-related, temporary neuronal degeneration (Ozcelik et al. 2000, Andreasen 1989). It is known that the neurovascular supply needs time to recover, and that it can take a pulp up to several months to regain sensory excitability (Gazelius et al. 1988). Furthermore, it should be noted, that EPT in permanent, but developing teeth with wide open apices may lack a positive response (Fulling and Andreasen 1976). This observation is attributed to incomplete innervation until the final stages of root development (Bernick 1964). For these reasons, a negative pulpal sensitivity response in teeth with RF must be interpreted with care. With respect to pulpal sensitivity tests in deciduous teeth, it must to be mentioned that they are known to be difficult to perform and even more difficult to interpret (Gopikrishna et al. 2009).

3.4.6 Radiographic imaging

The presence of a RF can only be confirmed (or excluded) radiographically (Wilson 1995). The radiographic appearance on a periapical radiograph is described as a radiolucent line separating the coronal from the apical fragment, or even multiple fragments from each other, and as a discontinuity of the periodontal ligament space (Figure 2.3.3a) (Whaites and Drage 2013).

Figure 3. (a) Periapical radiograph (orthogonal exposure) suggesting a complete root fracture at the mid-root level of the right permanent central incisor (black arrow). (b) More accurate depiction of the fracture plane in the same right central incisor by CBCT revealing cervical involvement (black arrow). Note: neither the periapical radiograph (a), nor the CBCT (b) reveal radiographic signs for inflammation. Hence treatment is not indicated.


a)
b)
30
20
10
0
-10
-20
-20
-10
0
10
20

If the radiolucent line continues in the same direction throughout several tooth roots, this is suggestive of an alveolar process fracture. Both, the plane of the RF (i.e. angulation), as well as the direction of the central beam, have an influence on the radiographic projection. If the central beam does not project in parallel through the fracture plane, the RF may remain covered on a radiograph due to superimposition. To compensate for this shortcoming, multiple radiographs at different vertical and horizontal angulations are advocated (Kullman and Al Sane 2012). Currently, there is no final agreement on the number of radiographs that are needed to confirm or exclude a RF. However, four radiographs (one orthogonal exposure, one steep occlusal exposure, and a mesial and distal excentric exposure) are recommended by a panel of experts and have shown to be more reliable in detection of RF compared to using fewer radiographs (Flores et al. 2007a, Wenzel and Kirkevang 2005).

Cone beam computed tomography (CBCT) has shown to be superior in detection of RF compared to conventional radiography (Cohenca et al. 2007). Suspected RF represent an indication for CBCT recommended by dental societies (Figure 2.3.3b) (2015). Particularly for primary teeth this might be the imaging modality of choice, because the roots of primary teeth are frequently masked by succedaneous teeth (Flores 2002). However, CBCT imaging requires a significantly higher radiation dose compared to conventional radiography (Pauwels et al. 2012). Therefore, especially in children and adolescents, an individual dose-risk assessment, must be taken into account. For further reading *see Chapter Dula*.

3.5 Treatment and Prognosis of Root Fractures

Emergency treatment of RF may require acute priority, i.e. treatment should be performed within a few hours after injury (Andreasen et al. 2002). Delayed treatment may lead to impaired periodontal healing and therefore undesired outcome. With respect to the injured pulpal and periodontal tissues, the coronal and apical fragment of a fractured root can be treatment-wise viewed as separate entities. In the majority of cases, treatment is only necessary for the coronal fragment. The most common therapy involves repositioning and temporary immobilization of the displaced coronal fragment. However, it is important to understand that all manipulations subsequent to a RF represent some form of additional trauma to the tissues involved. Consequently, it is of ultimate importance to perform these procedures as gently as possible (Andreasen et al. 2006).

3.5.1 General treatment considerations

Rinsing the soft-tissue wound with water to remove debris is advocated (Valente et al. 2003). Moreover, it may be necessary to remove dislodged objects from the soft-tissues to prevent local inflammation and to suture the soft-tissue wound. If pain is present, it should be managed by reasonable medication *(see Chapter Neuhaus)*. If the patients general condition does not require antibiotic prophylaxis, a routine prescription for inflammatory prophylaxis after RF injury is not supported by evidence and therefore not recommended (Andreasen et al. 1989, Andreasen et al. 2004a). See also *Chapter Chapuis* for further reading.

3.5.2 Treatment of periodontium

3.5.2.1 Root fractures *without displacement* of the coronal fragment

In RFs without displacement of the coronal fragment (i.e. a concussed, or subluxated fragment), the fracture line is usually located at the apical, or towards the mid-root, level. Hence, the periodontium provides sufficient support for the coronal fragment showing almost normal tooth mobility. In case of mild to moderate injury, such fractures may even remain unnoticed by the patient and clinician (Molina et al. 2008). Later on, these RFs can accidentally become evident during routine radiographic examination. Fortunately, RFs without displacement and increased mobility rarely require any form of therapy (Oztan and Sonat 2001, Cvek et al. 2002). In case of slight occlusal interference, minor adjustment to the antagonist and a soft diet for up to 2 weeks are advisable (Andreasen et al. 2007).

As indicated in Table 1, the overall prognosis of RFs depends upon certain patient and treatment-related factors. The prognosis of RFs without displacement of the coronal fragment is most favorable: the majority of cases develop hard tissue healing and maintain pulpal vitality (Andreasen et al. 1989, Andreasen et al. 2004b, Welbury et al. 2002).

3.5.2.2 Root fractures *with displacement* of the coronal fragment

A fractured and displaced coronal fragment may be intruded, extruded or laterally luxated. Moreover, the fragment may be either clocked in its position, or may show increased mobility on palpation. The fracture line is usually located at the mid-root level, or towards the cervical aspect of the root (Welbury et al. 2002, Calişkan and Pehlivan 1996, Hovland 1992). Whatever the displacement, the treatment of a displaced coronal fragment always aims to reposition the fragment to relieve periodontal and pulpal compression/stretching (Figure 1). Unless there is an alveolar process involvement, the repositioning of a RF rarely requires the injection of a local anesthetic. Subsequently, the coronal fragment should be stabilized using a semi-rigid splint. Semi-rigid orthodontic wires, or fiber-composites are appropriate materials and can be bonded to the coronal fragment as well as to the adjacent teeth. Splinting for 4 weeks has been shown to provide sufficient time for the periodontium to heal (Cvek et al. 2001). However, if the fracture line is located towards the cervical aspect of the root, and the fragment exhibits great mobility, a prolonged splinting time of up to 4 months may also be necessary to enable sufficient stability (Cvek et al. 2002). Moreover, treatment alternatives including the removal of the coronal fragment should be considered (Heithersay 1973, Heithersay and Moule 1982). *See also Chapter Krastl/Bühler.* In any case of splinting, the patient should receive appropriate oral hygiene instructions. If there is no microbial infection present, the majority of RFs with displaced crowns develop connective tissue healing at the fracture site (Andreasen et al. 2004b, Cvek et al. 2001). This healing pattern is less ideal but should be considered as acceptable.

3.5.3 Treatment of the pulp

3.5.3.1 Revascularization of the coronal fragment

The pulp of a coronal fragment survives RF injury in the vast majority (about 60-80%) of cases (Zachrisson and Jacobsen 1975a, Andreasen 1989, Calişkan and Pehlivan 1996). It must be reiterated that a negative response to pulpal sensitivity tests immediately after RF injury is a common finding and does not represent an indication for root canal treatment without further evidence of pulpal necrosis. No treatment (i.e. watchful waiting) also represents a form of treatment. In case of doubt, it is more advisable to monitor a case closely rather than to initiate treatment (Jacobsen and Kerekes 1980). A frequently observed reaction of a traumatized, but vital pulp, is pulp canal obliteration (Lundberg and Cvek 1980). The pulp continuously deposes hard-tissue (dentin) along the pulp canal walls leading to a narrowing of the entire pulpal space (Andreasen 1989). In case of RF, pulp canal obliteration is usually confined to the apical fragment, yet in rare cases the coronal fragment may be affected, too (Saroglu and Sonmez 2008). Pulp canal obliteration should be considered as a vital pulp's reaction to the trauma (Andreasen 1989). Affected teeth rarely develop pulpal necrosis (Robertson et al. 1996). Positive prognostic predictors for pulpal survival are given in Table 1.

3.5.3.2 Pulpal necrosis of the coronal fragment

Signs & symptoms for pulpal necrosis after RF are: an enduring negative response to pulpal sensitivity testing, presence of (pulpal) pain, pain on percussion, edema, sinus tract, progressive blackish discoloration of the tooth crown, and/or radiographic evidence for bone resorption, or arrested root development. Mostly, only the coronal fragment develops pulpal necrosis (Andreasen and Hjorting-Hansen 1967). Hence, in these cases *root canal treatment should be confined to this fragment only*. It should be noted that the apical terminus of a root fractured coronal fragment is wide-open. Therefore, an apexification procedure should be performed before obturation to avoid excessive overfill. Traditionally, this is done by long-term medication with calcium hydroxide (Cvek 1974, Cvek et al. 2004). However, this treatment option should be considered as outdated (Duggal et al. 2017). Because of its favorable characteristics and ease-of-use (eg. reduced number of visits), mineral trioxide aggregate (MTA) has been advocated for apexification procedures (Damle et al. 2012, Duggal et al. 2017). However, one has to be aware that some (but not all) MTA formulations are known to irreversibly stain teeth (Jacobovitz and de Pontes Lima 2009). After sufficient root canal treatment of the necrotic coronal fragment, the prognosis of root fractured teeth may be considered as promising (Cvek et al. 2008).

3.5.3.3 Pulpal necrosis of the apical fragment

In extremely rare cases of RF, the apical fragment may develop pulpal necrosis (Cvek et al. 2002). The tentative diagnosis can only be confirmed radiographically, since pulpal sensitivity tests are not possible there. It has been shown that conventional root canal treatment is not able to adequately seal off the root canal of the apical fragment (Cvek et al. 2004). Hence, combining endodontic treatment of the coronal fragment together with the surgical removal of the infected apical fragment is indicated in these rare cases (Cvek et al. 2004).

3.5.4 Treatment of root fractures in primary teeth

RF in primary teeth are rare (Majorana et al. 2002). Their treatment aim is, similar to that for permanent teeth, to facilitate periodontal and pulpal healing. However, the intervention in primary teeth should be reduced to the minimum. Moreover, therapeutic options may be limited because young children may display non-compliant behavior (Veire et al. 2012). If the coronal fragment is merely slightly displaced, it may be left untreated and will eventually realign spontaneously. The apical fragment will then resorb physiologically. Because of the anterior open bite, occlusive disturbances are rare. More severely displaced coronal fragments may be actively repositioned; however, extra care must be taken to not damage the succeeding tooth germ (Andreasen et al. 1971, Lenzi et al. 2015). The application of a bonded splint is usually not necessary. An exception is an accompanying alveolar process fracture, where the segment should be splinted for 2-3 weeks (Flores et al. 2007b). If the coronal fragment displays signs and symptoms of pulpal necrosis, it should be removed instantaneously to avoid potential damage to the permanent successor. Again, the apical fragment does not require therapy and will resorb physiologically. Unless there are no additional complicating factor, such as a recurring trauma for example, the prognosis of RFs in the primary dentition is comparable to those in the permanent dentition (Wilson 1995).

Table 1. Factors related to favorable pulpal (PU) and/or periodontal (PE) healing after root fracture injury.

Patient related factors	**Selected studies demonstrating a favorable effect**
Incomplete root development with open apical foramen (PU/PE)	Zachrisson and Jacobsen 1975b, Cvek et al. 2001, Andreasen et al. 2004b
No communication with oral environment (PU/PE)	Welbury et al. 2002
Positive pulpal sensitivity on testing immediately after RF injury (PU)	Andreasen et al. 1989, Cvek et al. 2002
RF line rather located towards the apical, than the cervical root level (PU/PE)	Cvek et al. 2008, Welbury et al. 2002, Andreasen et al. 2012b
Small distance between fragments (PU)	Andreasen et al. 2004b, Cvek et al. 2001
Physiologic mobility of the coronal fragment (PE)	Andreasen et al. 1989, Andreasen et al. 2004b
No, or merely slight displacement of the	Zachrisson and Jacobsen 1975a, Andreasen et al. 1989, Cvek et al. 2001

coronal fragment (PE)	
Treatment related factors	
Gentle application of a semi-rigid splint for a (short) period of approx. 4 weeks (PE)*	Andreasen et al. 1989, Andreasen et al. 2004a
Repositioning of the coronal fragment close to the natural position (PU/PE)	Andreasen et al. 2004a, Cvek et al. 2002
Root canal treatment confined to the pulp-necrotic coronal fragment only (PU)	Jacobsen and Kerekes 1980, Cvek et al. 2004
Using MTA for an apexification procedure rather than calcium hydroxide (PU)	Damle et al. 2012
* Alveolar process fracture, or RFs located towards the cervical root aspect with the coronal fragment exhibiting increased mobility, may require prolonged splinting (see running text).	

3.6 Recall

The patient should be recalled for clinical and radiographic examination at 1, 1.5, 4, 6, 12 months intervals, and again after 5 years (Diangelis et al. 2012). If possible, the splint should be removed after 4 weeks. The examinations should include the diagnostic procedures described above and aim to exclude periodontal inflammation and/or pulpal necrosis. Typically, signs of pulpal necrosis appear within the first 3 month after injury (Jacobsen and Kerekes 1980, Andreasen 1989). In addition, the emerging outcome may be evaluated. Hard tissue healing may be assessed radiographically by a vanishing fracture gap, and a positive response to pulpal sensitivity testing along with physiologic tooth mobility. In case of connective tissue healing, the fracture gap persists radiographically and blunting of the peripheral fracture edges can be observed (Andreasen and Andreasen 1988). Frequently, increased tooth mobility may persist for these teeth (Cvek et al. 2002, Zachrisson and Jacobsen 1975a). However, over time this effect has been shown to decline (Andreasen et al. 2012a). In contrast, interposition with granulation tissue is characterized by radiographic loss of the lamina dura, advancing rarefaction, and widening of the fracture line, along with clinical signs and symptoms of pulpal necrosis.

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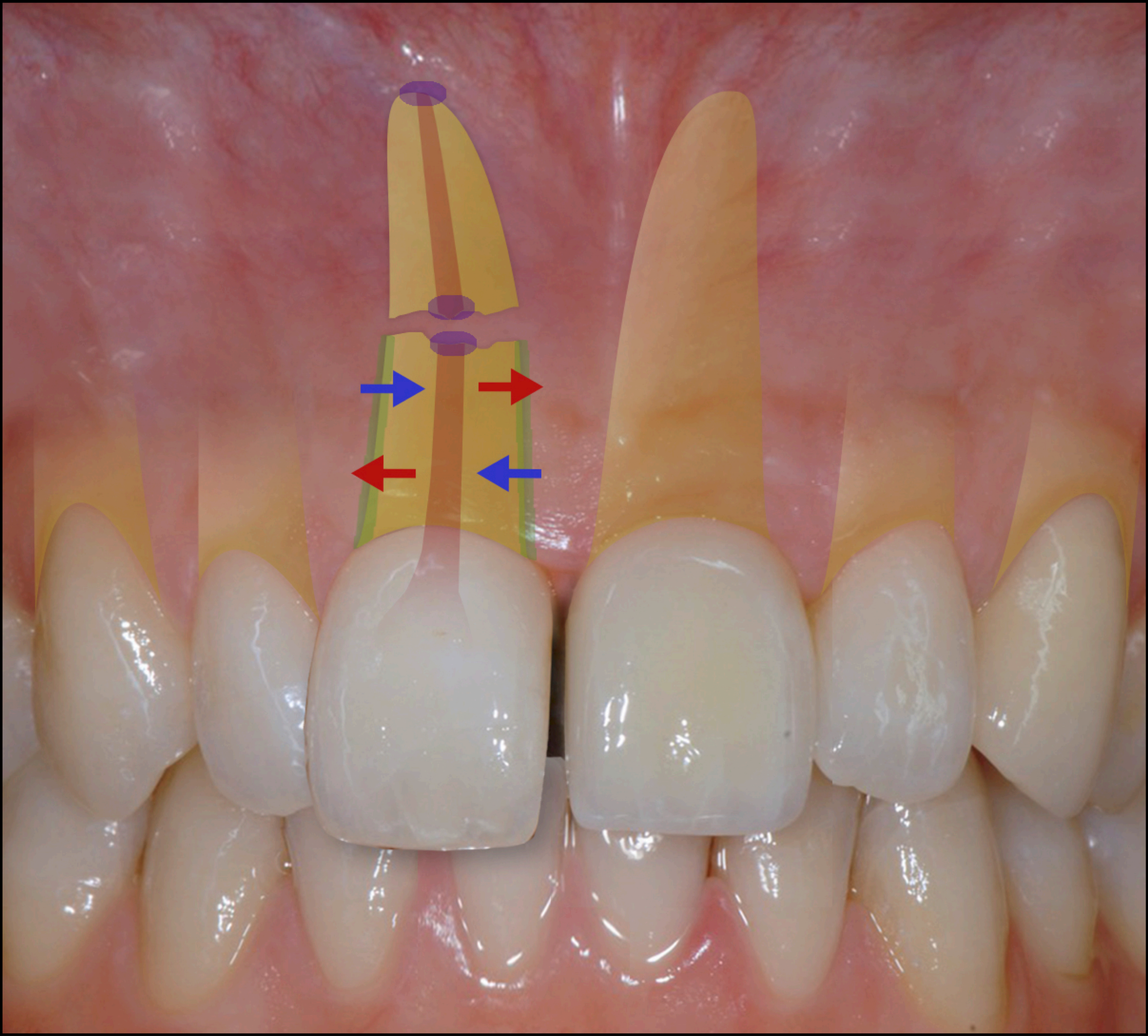

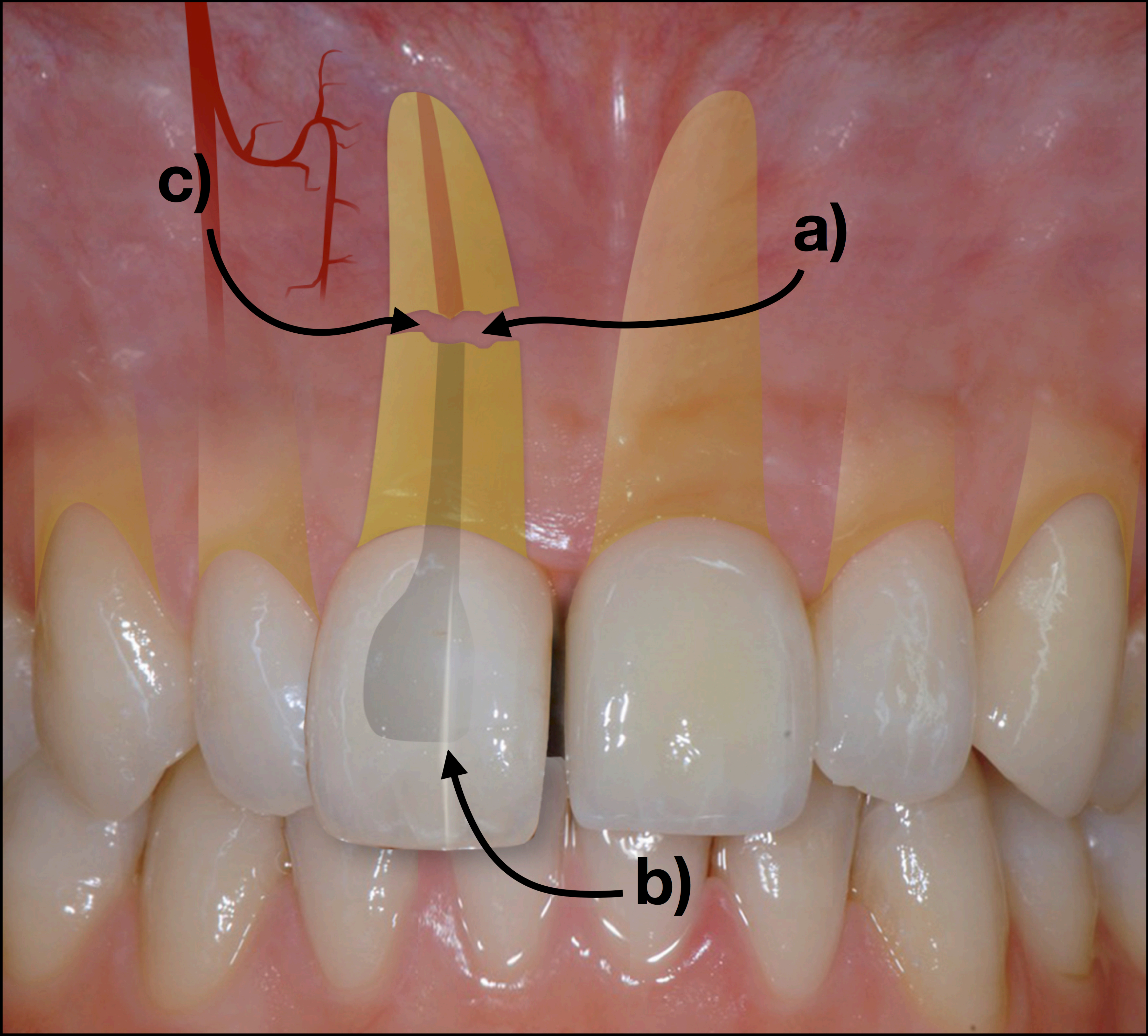
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